Available online at http://www.ijasrd.org/in

International Journal of Advanced Scientific Research & Development

Vol. 04, Iss. 02, Ver. I, Feb' 2017, pp. 15 – 21

e-ISSN: 2395-6089
p-ISSN: 2394-8906

SIMULATION OF AIR TURBULENCE THAT ORIGINS FOR THE PARTICULAR SOUND IN FLUTE USING LATTICE BOLTZMANN METHOD

Kaushal Patel

Department of Mathematics, Veer Narmad South Gujarat University, Surat.

ARTICLE INFO

Article History:

Received: 02 Jan 2017;
Received in revised form:
06 Feb 2017;
Accepted: 07 Feb 2017;
Published online: 07 Feb 2017.

Key words:

Lattice Boltzmann Method,
Flute,
Sound,
Turbulence.

ABSTRACT

Our aim is to understand how nature processes information. We can detect and describe the complex computational structure in natural processes and we can provide a quantitative characterization of essential aspects of sound generation in the flute which is the typical features of effect of turbulence inside the cavity. Aim of the study to establish the relation between the formations of particular sounds with inlet velocity and grove profile. This research is driven by the ever increasing amount of experimental data as delivered, to find internal effect cause to generate the sound together with change in the velocity and grove profile.

Copyright © 2017 Patel. This is an open access article distributed under the Creative Common Attibution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

INTRODUCTION

Nature has a very efficient way to process information. Processes studied by natural scientists involve systems that are either continuous, stochastic, spatially extended, or any combination of these, and fall strictly outside the range of discrete computation theory. The study of information processing in complex dynamical multiscale systems is, therefore, still in its infancy. This work is inspired from the wide complexity of the physical systems and consequently by the necessity to simplify their complexity into fundamental processes.

In recent years, the Lattice Boltzmann Method (LBM) has developed into an alternative and promising numerical scheme for simulating fluid flows and modelling physics in fluids. The scheme is particularly successful in fluid flow applications involving interfacial dynamics and complex boundaries. Unlike conventional numerical schemes based on discretization of macroscopic continuum equations, the lattice Boltzmann method is based on microscopic models and mesoscopic kinetic equations. The fundamental idea of the LBM is to construct simplified kinetic models that incorporate the essential physics of microscopic or mesoscopic processes so that the macroscopic averaged properties obey the desired macroscopic equations.

How to cite this article: Patel, K., (2017). "Simulation of Air Turbulence that Origins for the Particular Sound in Flute Using Lattice Boltzmann Method". *International Journal of Advanced Scientific Research & Development (IJASRD), 04* (02/I), pp. 15 – 21.

Historically originating from the lattice gas automata (LGA) introduced by Frisch, Hasslacher, and Pomeau [3], the lattice Boltzmann equation (LBE) has recently become an alternativemethod for computational fluid dynamics. The essential ingredients in any Lattice Boltzmann Models whichare required to be completely specified are: (i) a discrete lattice space on which fluid particles reside; (ii) aset of discrete velocities to represent particle advection; and (iii) a set of rules for the redistribution of particles residing on a node to simulate collision processes ina real fluid. Fluid-boundary interactions are usually approximated by simple reflections of the particles by solid interfaces.

In a hydrodynamic simulation by using the lattice Boltzmann equation, one solves the evolution equationsof the distribution functions of pretended fluid particles colliding and moving synchronously on a highlysymmetric lattice space. The highly symmetric lattice space is a result of the discretization of particlevelocity space and the condition for synchronous motions That is, the discretizations of time and particle phase space are coherently coupled together. This makes the evolution of the lattice Boltzmann equation very simple, it consists in only two steps: collision and advection. One immediate limitation of the LBE method is due to its use of highly symmetric regular lattice mesh, which is usually triangular or square lattices in two dimensions and cubic in three dimensions. Obviously this is a serious obstacle to its applications in many areas of computational fluid dynamics. To deal with complex computational domains, various proposals have been made to use grids that are better suited to fit boundaries or to adapt meshes according to the physics of the system.

It has been shown recently that the lattice Boltzmann equation is indeed a special finite difference form of the continuous Boltzmann equation with some drastic approximations tailored for hydrodynamic simulations [4, 5, 7]. This makes the lattice Boltzmann method more amenable to incorporate body-fitted meshes [8, 9] or grid refinement techniques [10]. In most cases the regular lattice mesh is abandoned by decoupling the spatial-temporal discretization and the discrete velocity set, so that interpolations can be used in addition to the advection on a non-regular or non-uniform mesh.

Figure I: Vertical Flute

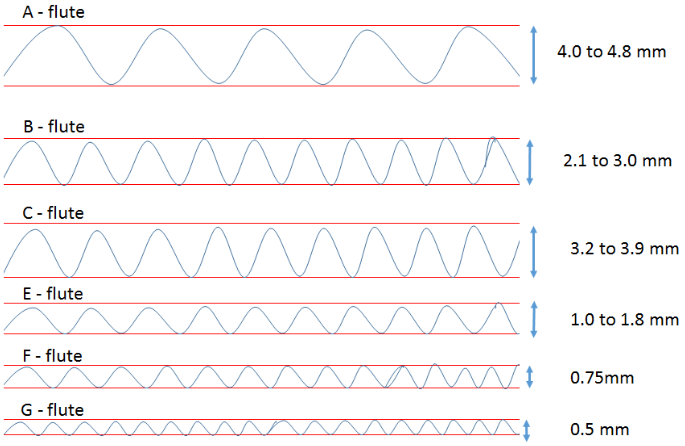


Figure II: Flute Size and their Classification

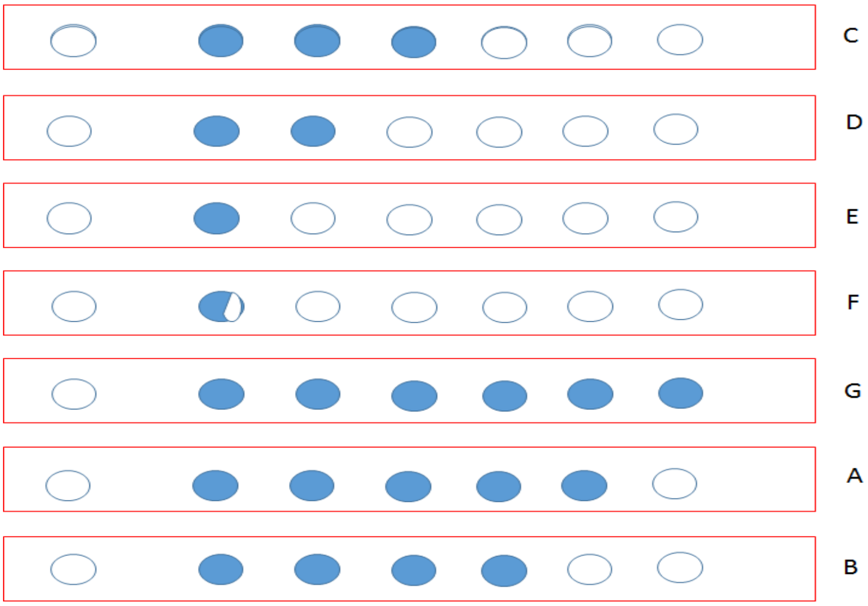


Figure III: Geometrical Representation of Cavity Generation

In this work Lattice Boltzmann Equation is used to simulate typical flow of airthrough cavity.

Flutes are unique woodwinds in their origin of sound. In order to produce sound, the pressure produced by the player's mouth must be above atmospheric pressure. Thus, in order to create sound, a player must use power (work/time). When derived, this is equivalent to a mass times acceleration (Force) times a change in displacement over time (P= (m a Δd)/t). The acceleration of the air stream results in higher or lower pitches. The displacement refers to how far the air stream travels down the flute without leaving through any of its holes. In order to make music, a constant supply of energy is given by the player, because energy is lost to friction on the wood or metal of the flute, and some leaves through its holes. This causes resonance, which determines the frequencies of the notes. In a vertical flute, one side of the mouthpiece is sharper than the other. The air stream strikes against it, creating vibrations. Vibrations are made by a second hole below the mouthpiece. The bottom of this hole is filed to a 45° angle to create resonance. The velocity of air affects the sound created. For example, a quicker velocity created a high pitch. The velocity increases with an increase in pressure. Pressure equals force per given area $(p = F/A)$. The force increases as a person blows harder, and the area decreases as a person tightens his/her lips. Thus, the pressure is increased.

To calculate the vibration of the air stream, one cycle is equal to the time for one pulse to travel over twice the total length of the flute. This accounts for both directions. The speed of sound in this case is "v," so the frequency is equal to the speed of sound divided by twice the length $\left(\frac{v}{2L}\right)$. In terms of harmonics, their frequencies are in increasing order in terms of "n." For example, the second harmonic has a frequency equal to $\left(\frac{2v}{2L}\right)$, the third $\left(\frac{3v}{2L}\right)$,… The picture above shows the first harmonic series on a flute tuned to C. Because its harmonics are in an even ratio (1:2:3:4:5:6:7:8:9:10), it sounds even and pleasing to the ear. This is called consonance.

Note Name	Note	Length (Units of Octave)	Factor to Multiply with Base Frequency	Frequency Generated by Note
C	Sa	1	1	65.4
D	Re	9/8	1.125	72.56
E	Ga	5/4	1.25	81.75
F	Ma	4/3	1.33	86.982
G	Pa	3/2	1.5	96.75
A	Dha	5/3	1.66	108.56
B	Ni	15/8	1.875	122.625

Table 1: Octave Frequency Table

THEORETICAL BACKGROUND

In this Lattice Boltzmann model we use the kinetic theory as a fundamental of Lattice Boltzmann equation. In kinetic theory we consider the hard sphere model with elastic collision. The position and the momentum of the molecules are defined as $x = (x, y, z)$ and $p = (p_x, p_y, p_z)$. Then $f(x, p, t)$ is the probability density function for the presence of molecule in six – dimensional phase space.

The probable no of molecules with position coordinates in the range$x \mapsto x \pm dx$and momentum coordinates $p \mapsto p \pm dp$ is given by $f(x, p, t)dxdp$. We introduce an external force F that is small relative intermolecular forces.If there are no collisions, then at time $t + dt$, the new positions of molecules starting at x are $x + \left(\frac{dx}{dt}\right)dt = x + dx$ and the new momentum is $p + Fdt = p + \left(\frac{dp}{dt}\right)dt = p + dp$. Thus, when the position and momentum are known at a particular time t, incrementing them allows us to determine at a future time $t + dt$. Then the updated particle velocity distribution function is defined as $f(x + dx, p + dp, t + dt)$. If the collision in not occurs then the particle velocity is not change then $f(x + dx, p + dp, t + dt) - f(x, p, t) = 0$ and if the collision occur then there is a change in velocity distribution function and it is described as $f(x + dx, p + dp, t + dt) - f(x, p, t) \neq 0$. The Boltzmann Equation Expresses a balance between transport of a particle and collision between particles then

$$\frac{Df}{Dt}_{Transport} = \frac{Df}{Dt}_{Collision}$$

$$\therefore \frac{\partial f}{\partial t} + p_\alpha \frac{\partial f}{\partial x_\alpha} = C(f)$$

Where $C(f)$ models the pair wise collision between particles.

$C(f)$ is evaluated by the Tailor's expansion of the updated velocity distribution function

$$dx\frac{\partial f}{\partial x} + dp\frac{\partial f}{\partial p} + dt\frac{\partial f}{\partial t} + \frac{(dx)^2}{2}\frac{\partial^2 f}{\partial x^2} + \frac{(dp)^2}{2}\frac{\partial^2 f}{\partial p^2} + \frac{(dt)^2}{2}\frac{\partial^2 f}{\partial t^2} + \frac{dxdp}{2}\frac{\partial^2 f}{dxdp}\frac{dpdt}{2}\frac{\partial^2 f}{dpdt} + \frac{dtdx}{2}\frac{\partial^2 f}{dtdx} = \Gamma^+ - \Gamma^-$$

$$dx\frac{\partial f}{\partial x} + dp\,\frac{\partial f}{\partial p} + dt\,\frac{\partial f}{\partial t} + \frac{(dx)^2}{2}\frac{\partial^2 f}{\partial x^2} + \frac{(dp)^2}{2}\frac{\partial^2 f}{\partial p^2} + \frac{(dt)^2}{2}\frac{\partial^2 f}{\partial t^2} + \frac{dxdp}{2}\frac{\partial^2 f}{dxdp}\frac{dpdt}{2}\frac{\partial^2 f}{dpdt} + \frac{dtdx}{2}\frac{\partial^2 f}{dtdx} = -\frac{f - f^{eq}}{\tau}$$

Then the equilibrium function is defined as $f^{eq} = \rho w_i\left[1 + \frac{3}{c^2}c_i u + \frac{9}{2c^4}(c_i u)^2 - \frac{3}{2c^2}u^2\right]$

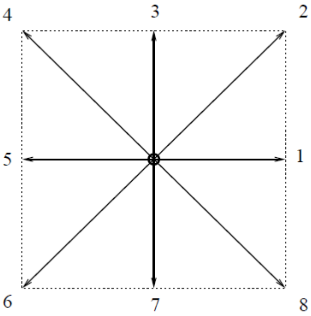


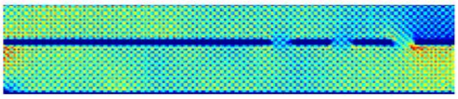
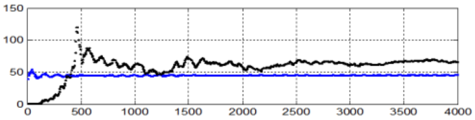
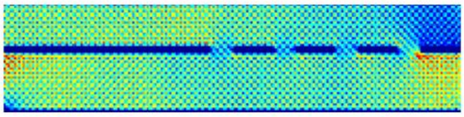
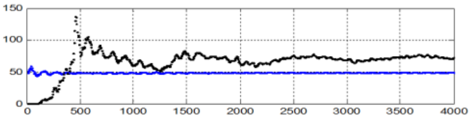
Figure IV: The Lattice Pattern of the D2Q9 Model

Wherew_i, the weight factor corresponds to set of particles for D2Q9 lattice for rest particle $w_0 = \frac{4}{9}$, nearest neighbours have $w_i = \frac{1}{9}$ for $i = 1,3,5,7$ and farthest neighbours having $w_i = \frac{1}{36}$ for $i = 2,4,6,8.c_i$is the discrete sets of velocities for D2Q9 lattice and is defined as $c_0 = 0$, nearest neighbours $c_i = c\left(\cos(i-1)\frac{\pi}{4}, \sin(i-1)\frac{\pi}{4}\right)$ for $i = 1,3,5,7$ and farthest neighbours $c_i = \sqrt{2}c\left(\cos(i-1)\frac{\pi}{4}, \sin(i-1)\frac{\pi}{4}\right)$for $i = 2,4,6,8$. We take the speed of light in the media $c = \sqrt{3w_0}\,\frac{\Delta x}{\Delta t}$ where $\Delta x\ and\ \Delta t$ is the lattice spacing and time spacing respectively. For these models we take single time relaxation parameter$\tau = 1$.

The macroscopic variables are defined as a velocity moments of the velocity distribution function

- Mass density: $\rho(x,t) = m\int f(x,p,t)\,d^3p$
- Flow velocity: $u(x,t) = \frac{m}{\rho}\int p\, f(x,p,t)\,d^3p$
- Temperature: $T = \frac{m}{2R\rho}\int |p|^2\, f(x,p,t)\,d^3p$
- Stress Tensor: $p_{\alpha,\beta} = m\int f(x,p,t)(p_\alpha - u_\beta)\, f(x,p,t)d^3p$

SIMULATION RESULTS

Note	Velocity distribution	Inlet /outlet average velocity
C		
D		

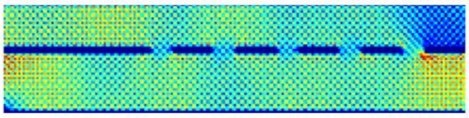
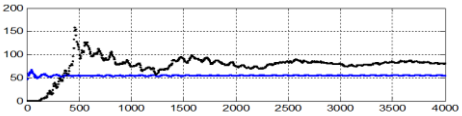
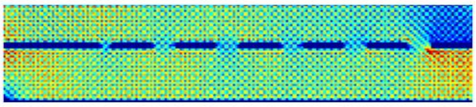
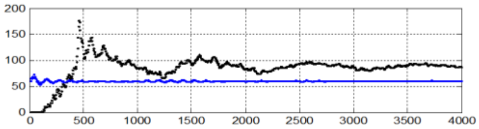
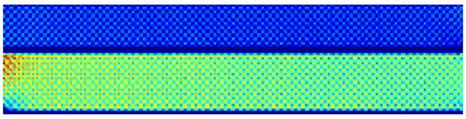
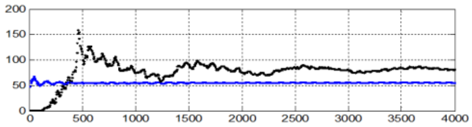
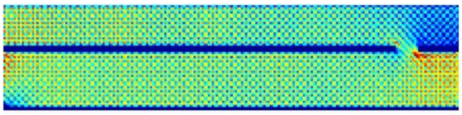
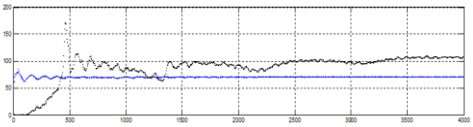
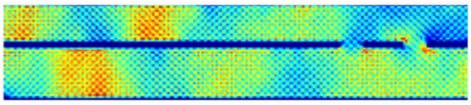
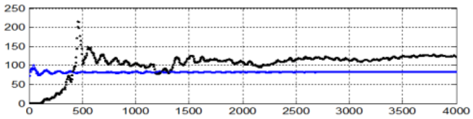
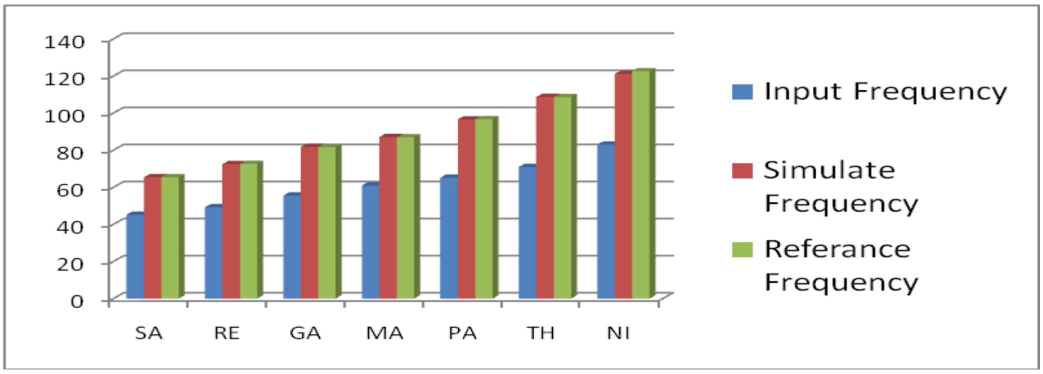
E		
F		
G		
A		
B		

Table 2: simulation of different note of flute at time t= 4000

Note Name	Note	Input Frequency	Flow Velocity	Output Frequency
C	Sa	45.23	75	65.394
D	Re	49.28	82	72.42
E	Ga	55.55	93	81.85
F	Ma	61	101.5	87.108
G	Pa	65.20	108.3	96.613
A	Dha	71	118	108.72
B	Ni	83	137.8	121.14

Table 3: Octave Frequency Table for Simulated Geometry



CONCLUSION

We simulate seven notes of flute as a diverse cavity models as depicted in figure III. Colum 2 in table 2 shows the turbulence generated by the different nodes and that origins for the particular sound in flute. Also in column 3 shows the average frequency at inlet (blue) and outlet (black) of the cavity. In table 3 demonstrate the inlet and outlet frequency generated by the notes that is a good argument with the simulated frequency and the reference frequency that can be shown in the above chart.

In this work we consider equilibrium function in the Lattice Boltzmann equation is considered up to the second order with can be good arguments between the accuracy of the solution and computational needs.

REFERENCES

[1] M. Bouzidi, D. Dominique, and P. Lallemand," Lattice Boltzmann Equation on a 2D Rectangular Grid" NASA/CR-2002-211658, ICASE Report No. 2002-18, June 2002

[2] M. Sukop and D. Thorne, "Lattice Boltzmann Modelling – An Introduction for Geoscientist and Engineers" Springer New York

[3] U. Frisch, B. Hasslacher and Y. Pomeau, "Lattice-gas automata for the Navier-Stokes equation", Phys. Rev. Lett., 56 (1986), 1505 1508.

[4] X. He and L. Luo, "A Priori Derivation of the Lattice Boltzmann Equation", Phys. Rev. E, 55 (1997), pp. R6333 R6336.

[5] Theory of the Lattice Boltzmann Method: From the Boltzmann Equation to the Lattice Boltzmann Equation, Phys. Rev. E, 56 (1997), 6811-6817.

[6] Lattice Boltzmann Model for the Incompressible Navier-Stokes Equation, J. Stat. Phys., 88 (1997), pp. 927-944.

[7] T. Abe, "Derivation of the Lattice Boltzmann Method by Means of the Discrete Ordinate Method for the Boltzmann Equation", J. Computat. Phys., 131 (1997), pp. 241-246.

[8] X. He and G. D. Doolen, "Lattice Boltzmann Method on a Curvilinear Coordinate System: Vortex Shedding Behind a Circular Cylinder", Phys. Rev. E, 56 (1997), pp. 434-440.

[9] Lattice Boltzmann Method on Curvilinear Coordinates System: Flow Around a Circular Cylinder, J. Computat. Phys., 134 (1997), pp. 306-315.

[10] O. Fillippova, and D. Hanel, "Grid Refinement for Lattice-BGK Models", J. Computat. Phys., 147 (1998), pp. 219-228.

[11] P. Lallemand, and L. S. Luo, "Theory of the Lattice Boltzmann Method: Dispersion, Dissipation, Isotropy, Galilean Invariance, and Stability", Phys. Rev. E, 61 (2000), pp. 6546 - 6562.

[12] I. V. Karlin, S. Succi and S. Orszag, "Lattice Boltzmann Method for Irregular Grids", Phys. Rev. Lett., 82 (1999), pp. 5245 - 5248.

[13] Y.H. Qian, D. D'Humires, and P. Lallemand, "Lattice BGK Models/or Navier-Stokes Equation", Europhys. Lett., 17 (1992), pp. 479 - 484.

[14] H. Chen, S. Ctten, and W.H. Niatthaeus, "Recovery of the Navier-Stokes Equations Using a Latticegas Boltzmann Method", Phys. Rev. A, 45 (1992), pp. R5339-R5342.

[15] M. Bouzidi, M. Firdaouss and P. Lallemand, "Momentum Transfer of a Lattice-Boltzmann Fluid with Boundaries", Phys. Fluids, 13 (2001), pp. 3452-3459.

[16] M. Schxfer and S. Turek, "Benchmark Computations of Laminar Flow Around a Cylinder, in Notes in Numerical Fluid Mechanics", Vol. 52 (ViewegVerlag, Braunschweig, 1996), pp. 547-566.

[17] J. Latt, "The Lattice Boltzmann Method: Complex CFD and Massive Parallelism" NASA Glenn Research Center Cleveland, Ohio, march 4, 2013.